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# Effect of LEO Cycling on 125 Ah Advanced Design IPV Nickel-Hydrogen Flight Cells—An Update

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# EFFECT OF LEO CYCLING ON 125 AH ADVANCED DESIGN IPV NICKEL-HYDROGEN FLIGHT CELLS-AN UPDATE

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## ABSTRACT

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An update of validation test results confirming the advanced design nickel-hydrogen cell is presented. An advanced 125 Ah individual pressure vessel (IPV) nickel-hydrogen cell was designed. The primary function of the advanced cell, is to store and deliver energy for long-term, low-earth-orbit (LEO) spacecraft missions. The new features of this design are: (1) use of 26 percent rather than 31 percent potassium hydroxide (KOH) electrolyte, (2) use of a patented catalyzed wall wick, (3) use of serrated-edge separators to facilitate gaseous oxygen and hydrogen flow within the cell, while still maintaining physical contact with the wall wick for electrolyte management, and (4) use of a floating rather than a fixed stack (state-of-the-art) to accommodate nickel electrode expansion due to charge/discharge cycling. The significant improvements resulting from these innovations are extended cycle life; enhanced thermal, electrolyte, and oxygen management; and accommodation of nickel electrode expansion. Six 125 Ah flight cells based on this design were fabricated by Eagle-Picher. Three of the cells contain all of the advanced features (test cells) and three are the same as the test cells except they do not have catalyst on the wall wick (control cells). All six cells are in the process of being evaluated in a LEO cycle life test at the Naval Weapons Support Center, Crane, Indiana, under a NASA Lewis contract. The catalyzed wall wick cells have been cycled for over 11 000 cycles with no cell failure in the continuing test. One of the noncatalyzed wall wick cells failed (cycle 9588).

## INTRODUCTION

As part of an overall effort to advance the technology of nickel-hydrogen batteries for use in a space power system an advanced design for an IPV battery cell was conceived. The intent of this effort was to improve cycle life at modest to deep-depths-of-discharge (40 to 80 percent). The approach was to review IPV nickel-

hydrogen cell designs and results of cycle life tests conducted in-house and by others to identify areas where improvements could result in a longer cycle life [2-8]. The feasibility of the advanced design was demonstrated using 6 Ah boiler plate cells and 31 percent KOH electrolyte [10]. Recently, a major LEO cycle life improvement using state-of-art design boiler plate cells, 26 percent KOH and an accelerated cycle regime was achieved under a NASA Lewis contract with Hughes [11-13].

The purpose of this experiment is to validate the advanced cell using flight hardware containing 26 percent KOH and compare cells containing the catalyzed wall wick to cells without it. Six 125 Ah capacity flight cells based on the advanced design were fabricated by Eagle-Picher Joplin, MO. Three of the cells contain all of the advanced features (test cells) and three are the same as the test cells except they don't have catalyst on the wall wick (control cells). They are undergoing real time LEO cycle life testing at the Naval Weapon Support Center (NWSC), Crane, Indiana under a NASA Lewis contract.

In this report results of storage, characterization, and cycle life testing of advanced cells with and without the catalyzed wall wick which were presented at the 1990 IECEC will be updated [14].

## EXPERIMENTAL

### Test Facility

The facility is capable of testing 45 battery packs with a maximum of 10 cells electrically connected in series per pack. Each pack has its own charge and discharge power supply which is controlled by a computer that is programmed to satisfy the particular test requirements. During testing each pack is scanned every 2.4 min to compare data such as voltage, temperature and pressure with programmed limits. If a parameter is out of limit

an alarm will be initiated and a message will be typed out identifying the cell and parameter. The data is recorded on a 132 mB disc drive and if requested can be obtained in report form. The cell temperature during a test is controlled by a recirculating cooler that circulates a solution of water and ethylene glycol through a cooling plate.

### Cell Description

The six cells are 125 Ah capacity advanced flight IPV nickel-hydrogen cells. They were fabricated by Eagle Picher, Joplin according to NASA Lewis Research Center specification using nickel electrodes fabricated at Eagle Picher, Colorado Springs and were impregnated with active material by the alcoholic Pickett process [15]. Three of the cells (test cells) contain all of the advanced design features as described in reference 1. The other three cells (control cells) are the same as the test cells except they do not have catalyst on the wall wick. All six cells contain 26 rather than 31 percent KOH electrolyte.

The test cell design is illustrated in figure 1. The new features of this design which are not incorporated in the state-of-the-art Air Force/Hughes or Comsat/Intelsat Cells are: (1) use of 26 percent rather 31 percent KOH electrolyte which improves cycle life [11-13], (2) use of a catalyzed wall wick located on the inside surface of the pressure vessel wall. It is used to chemically recombine the oxygen generated at the end of charge and on overcharge with hydrogen to form water. State-of-the-art nickel hydrogen cells recombine the oxygen on the catalyzed hydrogen electrode surface in the stack. The catalyzed wall wick should improve oxygen and thermal management [16], (3) the use of serrated edge separators to facilitate gaseous oxygen and hydrogen flow within the cell, while still maintaining physical contact with the wall wick for electrolyte management, (4) Use of a floating rather than a fixed stack (SOA) to accommodate nickel electrode expansion due to charge/discharge cycling. This is accomplished by use of Belleville disc springs located at each end of the stack. The significant improvements resulting from these innovations are extended cycle life, enhanced oxygen, thermal and electrolyte management, and accommodation of some of the nickel electrode expansion.

### Measurements and Procedures

The quantities measured every 2.4 min for each cell during charge and discharge and their accuracies are: current ( $\pm 2.0$  percent), voltage ( $\pm 0.001$  percent), pressure ( $\pm 1$  percent), and temperature ( $\pm 1$  percent).

Charge and discharge ampere-hour quantities were calculated from current and time. The charge to discharge ratio (ampere-hours into cell on charge to ampere hours out on discharge) are calculated from the charge and discharge ampere-hour capacities. Cell charge and discharge currents are calculated from measured, voltage across a shunt, using an integrating digital voltmeter. Cell voltage is measured, also using an integrating digital voltmeter. Cell pressure is measured using a strain gauge located on the cell dome. The temperature is measured using a thermistor located on the center of the pressure vessel dome. The thermistor is mounted using a heat sink compound to insure good thermal contact.

After completion of activation testing by the manufacturer the precharge hydrogen pressure was set to 0 psig (14.5 psia) with the nickel electrodes in the fully discharged state. After completion of the acceptance testing the cells were discharged at the C/10 rate (12.5 A) to 0.1 V or less and the terminals were shorted. The cells were shipped to NWSC, Crane, where they were stored open circuit, discharge, 0 °C for 52 days. After storage the discharge ampere-hour capacity acceptance test was repeated. The capacity was measured after charging the cells at the C/2 rate (62.5 A) for 2 hr, then C/10 for 6 hr, followed by a 0.5 hr open circuit stand. The discharge capacity was measured to 1.0 V for each of the following rates: C/2, C, 1.4C, and 2C.

Prior to under going cycle life testing the capacity retention after a 72 hr open circuit stand (10 °C) was measured for all cells. For the cycle life test the cells were connected electrically in series to form a six cell pack. The cycle regime is a 90 min LEO orbit consisting of a 54 min charge at a constant 0.69C rate (87A) followed by a 36 min discharge at C rate (125A). The charge to discharge ratio was 1.04. The depth-of-discharge was 60 percent of name plate capacity (125 Ah). During the cycle life test the cooling plate temperature was maintained at  $10 \pm 2$  °C. Cell failure for this test was defined to occur when the discharge voltage degrades to 1.0 V during the course of the 36 min discharge.

## RESULTS AND DISCUSSION

### Cell Performance

For a representative 125 Ah advanced catalyzed wall wick nickel-hydrogen flight battery cell the voltage and pressure during charge and discharge are shown in figure 2 (beginning of life). The discharge rate was 0.69C (87A) and the temperature was a nominal 10 °C. The

mid discharge voltage was 1.248 V. The pressure, as expected varies linearly with the state-of-charge. It should be noted, however, that the pressure could increase with charge/discharge cycling causing a shift in the state-of-charge curve.

The effect of discharge rate on ampere-hour capacity for a representative cell of each type is shown in figure 3. The capacity decreased slightly (1 percent) over the range of C/2 to 1.4 C, after which point it decreases rapidly. In a nickel-hydrogen cell the gaseous hydrogen comes into contact with the nickel electrodes resulting in a capacity loss due to self discharge. The capacity retention of the cells after a 72 hr open circuit stand at 10 °C is shown in figure 4. The data show that there is no significant difference in capacity retention between the catalyzed and noncatalyzed wall wick cells. For the catalyzed wall wick cells on the average it is 84 percent and for the noncatalyzed wall wick cells it is 85 percent.

#### Storage Test

The effect of storage (52 days, discharged, open circuit, 0 °C) on the capacity of the six, 125 Ah flight IPV nickel-hydrogen cells is summarized in figure 5. The spread in the data show that there is no significant capacity loss for either the 26 or 31 percent KOH cells due to the 52 day storage. Actually there was a slight average increase in capacity for both the catalyzed and noncatalyzed wall wick cells after the 52 day storage.

#### Cycle Test

The influence of LEO cycling at 60 percent DOD on the end of discharge voltage for the 125 Ah catalyzed wall wick IPV nickel-hydrogen flight cells is summarized in figure 6. After 11 000 cycles there has been no cell failure in the continuing test. The influence of cycling on the end of charge pressure for the catalyzed wall wick cells is shown in figure 7. No pressure for cell 2 is available because the cell had a bad strain gauge. For the two cells the pressure increased relatively rapidly up to about cycle 1400 then decreased. The average pressure increase at cycle 1400 is about 11 percent higher than at the beginning of life.

The influence of LEO cycling at 60 percent DOD on the end of discharge voltage for the 125 Ah noncatalyzed wall wick IPV nickel-hydrogen flight cells is shown in figure 8. One of the three cells failed (cycle 9588). The failure was characterized by degradation of end of discharge voltage to 1.0 V. The cell did not fail due to an electrical short. The influence of cycling on the end of charge pressure for the noncatalyzed wall wick cells

is shown on figure 9. The pressure increased for the three cells up to about cycle 2000 then decreased. The average pressure increase at cycle 2000 is about 9 percent higher than at the beginning of life.

The cycle life testing will continue until cell failure. A post-cycle teardown and failure analysis will be conducted to evaluate the cause of failure. This information will be used to effect further improvements.

#### CONCLUDING REMARKS

Validation testing of NASA Lewis 125 Ah advanced design IPV nickel-hydrogen flight cells is being conducted at NWSC, Crane under a NASA Lewis contract. This consists of characterization, storage and cycle life testing. There was no capacity degradation after 52 days of storage with the cells in the discharged state, on open circuit, 0 °C, and a hydrogen pressure 14.5 psia. The catalyzed wall wick cells have been cycled for over 11 000 cycles with no cell failures in the continuing test. One of the noncatalyzed wall wick cells failed.

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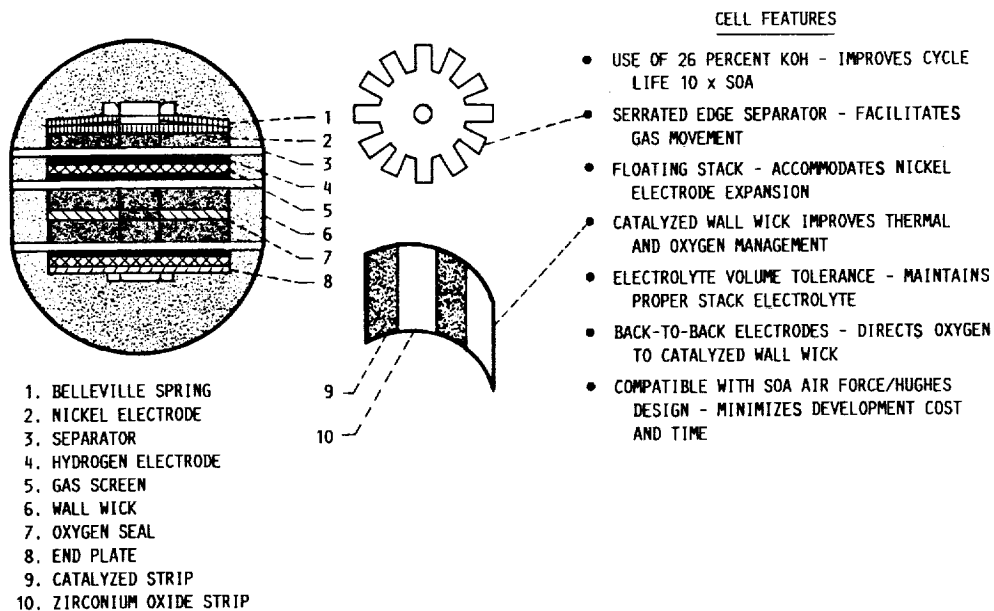


FIGURE 1. - NASA ADVANCED DESIGN IPV NICKEL-HYDROGEN CELL-CATALYZED WALL WICK.

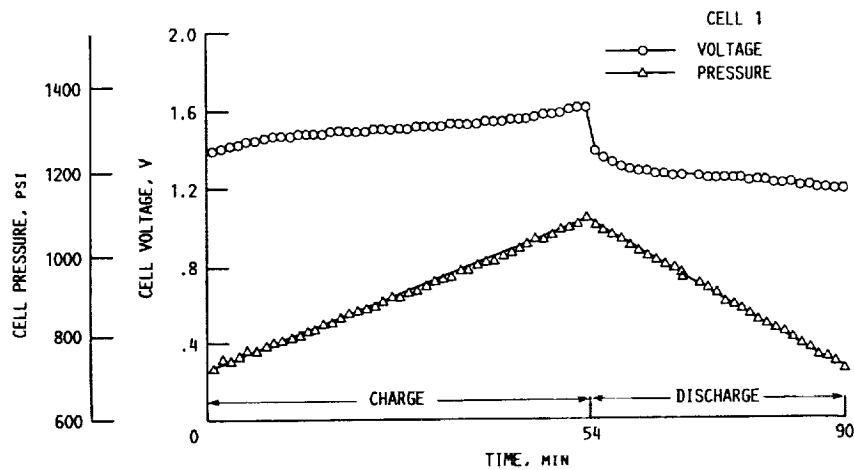


FIGURE 2. - CELL VOLTAGE AND PRESSURE DURING CHARGE AND DISCHARGE FOR A REPRESENTATIVE 125 A-hr ADVANCED CATALYZED WALL WICK IPV Ni-H<sub>2</sub> FLIGHT BATTERY.

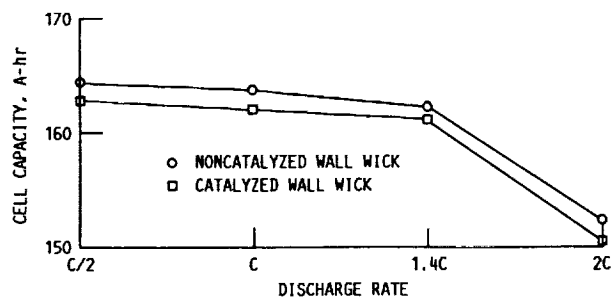


FIGURE 3. - COMPARISON OF EAGLE-PICHER 125 A-hr Ni-H<sub>2</sub> CELLS CATALYZED AND NONCATALYZED WALL WICK.

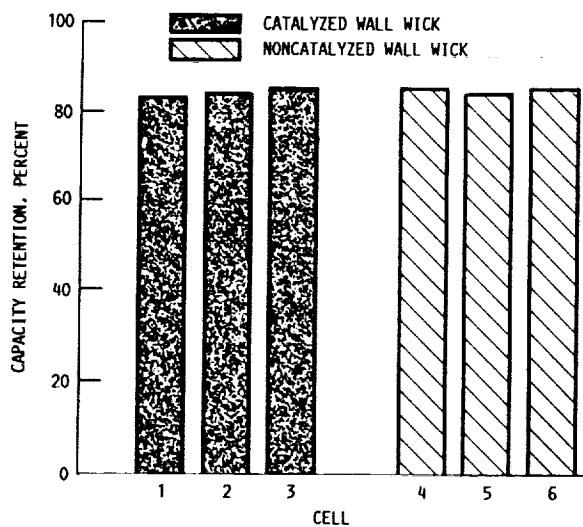


FIGURE 4. - CAPACITY RETENTION OF 125 A-hr EAGLE-PICHER ADVANCED IPV Ni-H<sub>2</sub> FLIGHT CELLS AFTER 72 HOUR OPEN CIRCUIT STAND.

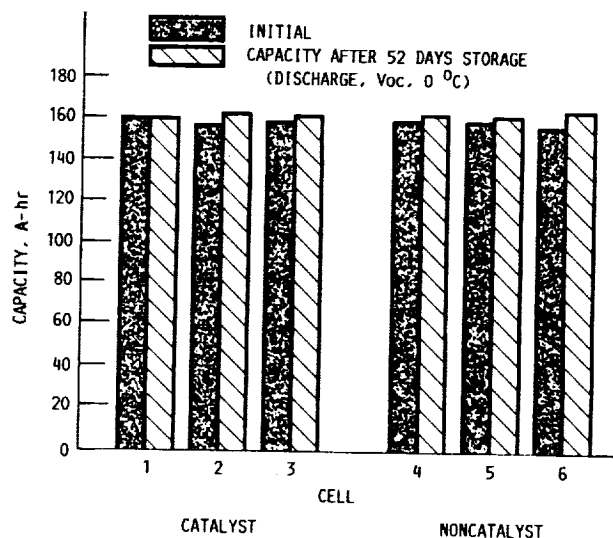


FIGURE 5. - EFFECT OF STORAGE ON CAPACITY OF 125 A-hr EAGLE-PICHER ADVANCED FLIGHT IPV Ni-H<sub>2</sub> CELLS. CATALYZED AND NONCATALYZED WALL WICK, 26 PERCENT KOH.

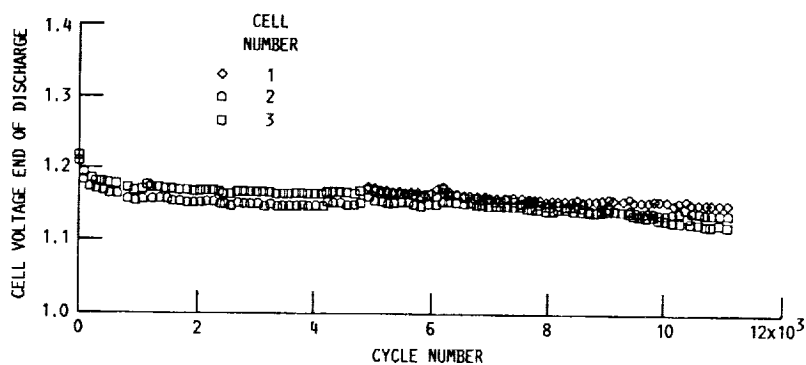


FIGURE 6. - EFFECT OF LEO CYCLING ON 125 Ah NASA LEWIS ADVANCED CATALYZED WALL WICK IPV Ni-H<sub>2</sub> CELLS MANUFACTURED BY EAGLE PICHER - 26 PERCENT KOH, 60 PERCENT DOD, 10<sup>0</sup>C.

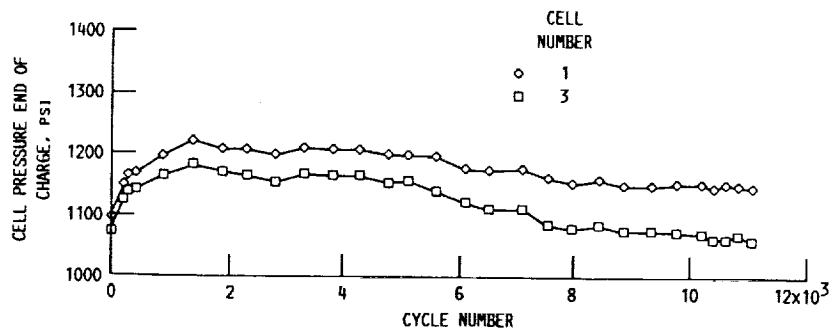


FIGURE 7. - EFFECT OF LEO CYCLING ON 125 Ah NASA LEWIS ADVANCED CATALYZED WALL WICK IPV Ni-H<sub>2</sub> CELLS MANUFACTURED BY EAGLE PICHER - 26 PERCENT KOH, 60 PERCENT DOD, 10<sup>0</sup>C.



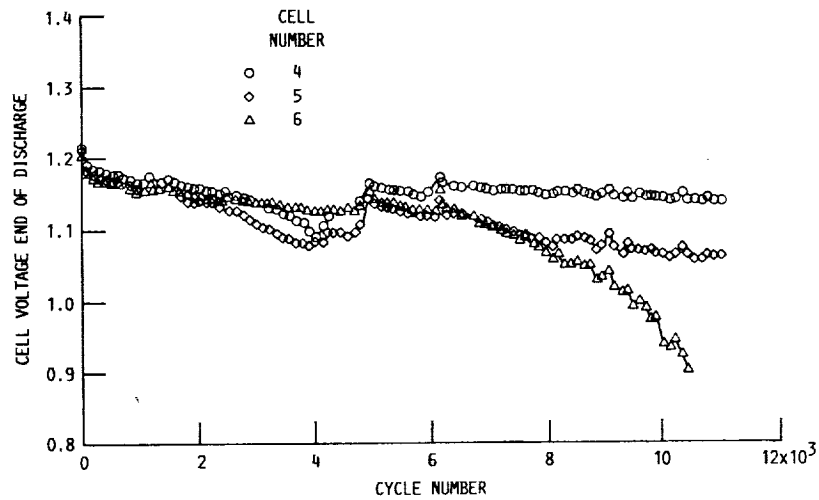


FIGURE 8. - EFFECT OF LEO CYCLING ON 125 Ah NASA LEWIS ADVANCED NONCATALYZED WALL WICK IPV  $\text{Ni}/\text{H}_2$  CELLS MANUFACTURED BY EAGLE PICHER - 26 PERCENT KOH, 60 PERCENT DOD,  $10^\circ\text{C}$ .

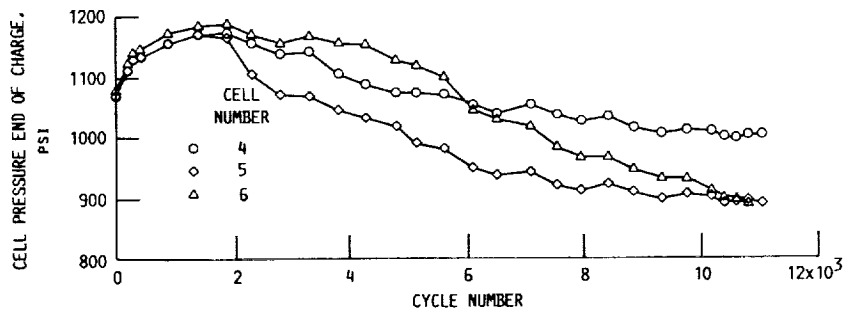


FIGURE 9. - EFFECT OF LEO CYCLING ON 125 Ah NASA LEWIS ADVANCED NONCATALYZED WALL WICK IPV  $\text{Ni}/\text{H}_2$  CELLS MANUFACTURED BY EAGLE PICHER - 26 PERCENT KOH, 60 PERCENT DOD,  $10^\circ\text{C}$ .



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